16.—THE WATER EXTRACTS OF WESTERN AUSTRALIAN SOILS.

No. 1.

Studies on Soils from Merredin, Ghooli, Salmon Gums, Wongan Hills, Chapman, Baker's Hill and Lake Brown.

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INTRODUCTORY.

In presenting the subject of the composition of the water extracts of certain of the soils of this State to the people of Western Australia, it seems desirable, at the outset to touch upon the main ideas and contributions which have led to the present status of our knowledge in this field. It is the object of the writer to prove in these introductory remarks the importance of the soil solution as the direct source of at least the bulk of the minerals absorbed by plants. It will be shown that the subject is not new and that direct contributions have been made since about 1860.

The first advances in the science of plant nutrition were due to the efforts of Theodore de Saussure (4)* a Swiss who published his views and experimental data in 1804. He showed *quantitively* that certain minerals were absorbed from the soil and that the carbon dioxide of the air supplied the carbon needs of plants. De Saussure's views were not acceptable to the agricultural chemists of the day and it was not until the great German chemist Justus von Liebig (8), some 30 years later adopted the main features of his thesis and embodied them in his forceful writing, that the knowledge of the mineral requirements of plants was of much interest to investigators. Many of the essentials of Liebig's teachings are acceptable to-day.

However, Liebig believed that the aqueous solution in the soil was inadequate to supply the mineral needs of plants. He argued, in 1863, that "the power of the soil to nourish cultivated plants is therefore in exact proportion to the quantity of nutritive substances which it contains in a state of physical saturation." (Russell, E. J., "Soil conditions and Plant growth," 1921, p. 154). Also he believed that the yield was governed by the necessary constituent in least amount (physiologically) in the soil—(Law of the minimum). Unfortunately, the great complexity of the soil

* Figures in brackets refer to literature cited.

system was not realised at this time and in the course of a few years the results of the field experiments of Lawes and Gilbert at Rothamsted and of Ville and others in France led to the discrediting of Liebig's "Mineral Theory."

Meanwhile certain agricultural chemists and others interested in the subject were busily studying the liquid phase of the soil. Eichhorn (5) in Germany, used the water extraction method to study a soil from Bonn and concluded, from his results, that the soil contained sufficient water soluble constituents to meet the needs of a growing crop. Although these results were criticised by Liebig's followers, other workers in Germany were able to substantiate Eichhorn's views. The next great advance was made in France by Schloesing (13) who studied the solutions *displaced* from the soils by allowing coloured rain water to percolate through a compact column of moist soil. This method, with modifications and improvements, has been one of the most fruitful in affording information concerning the soil solution. Schloesing and his son (14) concluded that the soil solution supplied at least the major portion of the mineral constituents absorbed from the soil by plants.

The question of root secretions is still with us. Liebig (8) believed that acetic acid excreted by the roots *dissolved* the absorbed minerals. Early investigators placed much importance on the experiment showing the etching of polished marble by growing roots. However, Czapek (3) in 1896 showed that the effect was due to carbonic acid, because, in the first place, plates made of aluminium phosphate and plaster of Paris were not attacked, thus eliminating acids stronger than citric, tartaric or malic; in the second place, the secretions turned congo red a brownish red. The presence of acetic acid causes the development of a blue colour while carbonic acid produces the brownish red colour with congo red as obtained. Recent work by F. W. Parker (9, 10) indicates that there is no relation between absorption of minerals and the total production of carbon dioxide in a soil. However, no one has yet been able to measure the effectiveness, if any, of the carbon dioxide produced by the root hairs in intimate contact with the soil particles. Be that as it may, the soil solution (as extracted from the soil) seems to approximate the "physiological" soil solution.

The concentration of the soil solution is due in part to the solvent action of water on the soil minerals, and in greater measure to the nitric and sulphuric acids produced by bacteria as end products in the decomposition of organic matter. Soils differ greatly in respect to both the composition and concentration of the solution and in general the sequence of vegetation types in any one zone is related in particular to the nature of the soil solution.

It is interesting to note that an error on the part of certain prominent American investigators led to renewed activity in soil solution studies in the early part of the present century. Whitney and Cameron (16) argued that, as most soils contain practically the same minerals in the solid phase, the soil solution must be a saturated solution of these minerals and must be practically uniform in composition and concentration in all soils. This was perfectly good chemistry, but was in error as the propounders overlooked the fact that the soil is primarily a biological laboratory. In a short time papers appeared, notably from Rothamsted (6) and the United States, controverting this thesis. At the present time, a bibliography of the important papers on the soil solution would run into hundreds. The principal contributions now come from America, Germany and Russia. Several States in Australia are using methods of studying the soil solution in connection with their problems.

The concentration of the solution in most soils ranges from about 100 p.p.m. to 4,000 p.p.m. of the soil solution. Expressed in terms of the dry soil this would amount to from 20 to 800 p.p.m. Alkali soils are not normal as the solution is excessively enriched as a result of outside agencies such as seepage and evaporation, deposition of salts in the rain, etc. Typical examples of the concentration and composition of the soil solutions from American soils are given in Table 1. It will be seen that the soil solution is by no means of constant composition or concentration. Also the bulk of the anions (nitrate and sulphate) are of biological origin.

TABLE 1.

THE COMPOSITION OF THE SOIL SOLUTION.

ppm Soil Solution.

Soil.	pH.	SO_4.	NO_3.	Cl.	PO_4.	Ca.	Mg.	K.
California 7B	7·6	454	1,781	55	1·2	672	134	38
California 33 (15)	7·0	...	50	...	0·2	50	...	...
California Madera	7·3	140	47	...	4·5	119	129	57
Oregon 1	...	Trace	75	...	...	83	...	15
Oregon 2	...	50	137	...	...	64	...	12
Rothamsted (6)	...	...	...	...	0·6	...	...	3·4

Of course this Table does not give a complete picture of the soil solution. In addition to these substances will be found about fifteen elements among which are iron, manganese, iodine, nickel, zinc, boron, aluminium, silicon, vanadium, copper, etc. These elements are present in minute amounts but normally in physiologically sufficient quantities.

The use of amendments of various kinds to increase the soil fertility has been practised since earliest times. The amendments may have a physical effect, a chemical effect, or most probably, both. The simplest fertiliser works profound changes in the composition of the soil solution, as a result of direct chemical reactions with the soil and also as a result of changed biological conditions. Thus lime not only neutralises acidity or sourness, but increases the phosphate content of the soil solution in many instances. In addition, potassium, magnesium and other elements may be brought into solution while others, *e.g.*, manganese are precipitated causing physiological disorders such as chlorosis. A study of Table 2 indicates the complexities of fertiliser treatments and also that fertilisers directly increase the concentration of various elements in the soil solution.

TABLE 2.

EFFECT OF FERTILISERS ON THE COMPOSITION OF THE SOIL SOLUTION.

ppm Soil Solution.

*ppm Dry Soil—Water extract.

—	pH.	PO_4.	SO_4.	NO_3.	Ca.	Mg.	K.	Na.	Mn.
California 30 (15)—									
Untreated ...	7·0	7·2	97	576	207	64	...	...	0·16
Sulphur (1500 ppm 90 days)	3·2	38·0	8920	536	600	1310	...	...	250
Oregon (11)—									
Untreated ...	6·2	4.0	253	116	144	119	98	...	...
K_2SO_4 (540 lbs. per acre)	6·1	3·0	294	157	116	113	172	...	...
Untreated ...	6·7	4·0	161	70	172	91	60	...	...
$(NH_4)_2SO_4$ (410lbs. per acre)	5·4	4·0	205	150	227	121	63	...	...
California 1C *(1)—									
Untreated ...	...	5·3	125	297	105	38	42	96	...
22K + $77NO_3$ + $10PO_4$	...	4·6	159	338	119	56	49	115	...
75K + $117NO_3$ + $61PO_4$	...	8·6	278	350	126	44	80	102	...
435K + $687NO_3$ + $357PO_4$	...	30·0	692	692	237	102	165	112	...
Tankage ...	...	6·7	153	592	146	52	61	110	...

The effect of the crop in modifying the soil solution has been amply discussed in papers from the University of California (14, 2). As a result of crop growth the soil solution is practicaly depleted of nitrate, while calcium, potassium, phosphate, etc., are significantly reduced in concentration.

Having discussed the soil solution as the phase of immediate physiological importance some brief mention must be made of the methods in use for obtaining the soil solution for purposes of study.

1. The Water Extract.

The soil is extracted with a known proportion of distilled water and filtered. The filtrate is then examined by the usual chemical methods. Studies by Stewart (14) Hoagland et al (7) indicate that the water extract gives a very good picture of the true soil solution. As no special apparatus is required this method has been adopted in the studies here reported. In order to minimise the direct solubility effects on the soil minerals, a narrow ratio of one part of soil to two parts of water is used.

2. The displaced solution is obtained by modifications of Schloesing's (12) method, using alcohol, kerosene or water as the displacing medium and air pressure to increase the rate of displacement.

3. The expressed solution probably accurately represents the true soil solution. The moist soil is pressed in a hydraulic press and the liquid obtained analysed.

In addition to these more or less direct methods, the concentration of the soil solution may be determined indirectly by the use of physical methods. The total concentration may be computed from the freezing point lowering the soil and the content of electrolytes by measurement of the resistance to the flow of electricity through the soil or soil extract.

1.—Studies on Soils from the State Farms at Merredin, Ghooli, Salmon Gums, Wongan Hills, and Chapman, and from Baker's Hill and Lake Brown.

The Soils used.

The soils from the State Farms were obtained from the headlands adjacent to the Rate of Superphosphate plots in 1928. The surface soil (A. horizon) was sampled at five different places along the width of the plots and a composite sample made. The following general observations describe the soils used:—

1. *Merredin.*—A dark brown clay loam from 10in. to 12in. deep. The marked accumulation of clay and calcium carbonate below this depth indicates a mature profile. The main timber was Salmon-gum (Eucalyptus salmonoploia) and Gimlet (E. salubris).
2. *Ghooli.*—a red silty clay loam from gently rolling forest land.
3. *Salmon Gums.*—Greyish brown, calcareous loam, bearing mallee. This soil contains an appreciable amount of sodium chloride and represents a type of mallee lands of the Esperance area.
4. *Wongan Hills.*—A grey sand containing a small amount of sticky clay. The soil carried a low scrub and represents one of the many types of light lands of Western Australia.
5. *Chapman.*—A red sandy loam from a small flat near a creek. It was probably formed through the agency of the creek and is of "recent" origin. The soil is formed from rocks of the granite type and carried jam (Acacia acuminata) with some scrub.
6. *Baker's Hill.*—The soils represent two types from the higher levels of the Darling Range. Samples 1, 2, and 3 are white sands while sample 4 is a black creek bottom soil.
7. *Alkali Soils.*—Representing samples from Lake Brown. Samples 2, 3, 4, and 8 are chocolate soils of a silt loam texture carrying a Morrell (Eucalyptus sp.) as the principal timber. Sample 10 represents a fertile dark brown clay loam carrying gimlet (E. salubris) and is given for purposes of comparison.

The Composition of 1 : 2 Water Extract.

The extract was prepared by mixing one part of soil with two parts of water by weight and filtering under suction. The extracts were analysed by standard methods adapted for the purpose. The reactions expressed as pH were determined colorimetrically. The results of the analyses are reported in Tables 3 and 4.

TABLE 3.

COMPOSITION OF WATER EXTRACTS OF SOILS OF WESTERN AUSTRALIA.

1 : 2 WATER EXTRACTS. ppm Dry Soil.

Locality.	pH.	NO_3.	SO_4.	PO_4.	Cl.	HCO_3	Ca.	Mg.	Mn.
Merredin	7·4	193	41	?	204	80	31	125	*Nil*
Ghooli	7·4	59·5	...	?	196	108	11	...	*Nil*
Salmon Gums ...	8·0	39·7	...	?	568	320	44	...	*Nil*
Wongan Hills ...	7·1	10·9	31	?	60	34	13·5	44	Trace
Chapman	6·4	5·9	49	?	24	36	18	50	*Nil*
Baker's Hill—									
1	6·6	19	...	Trace	20	32	0	6·2	...
2	6·6	22	...	0·09	20	32	0	5·2	...
3	6·9	38	...	0·12	8	36	0	4·4	...
4	7·2	26	...	0·06	28	44	6·0	6·2	...

TABLE 4.

COMPOSITION OF WATER EXTRACTS OF ALKALI SOILS (WEST. AUS.).

1 : 2 WATER EXTRACTS.

ppm Dry Soil.

(Analyses made by Government Analyst, 24–10–28.)

—	pH.	NO_3.	SO_4.	Cl.	CO_3.	Ca.	Mg	K.	Na.
Lake Brown—									
2 and 3 ...	7·6	602	426	1,698	84	161	96	44	1,199
4 and 8 ...	7·9	205	158	889	108	113	34	57	583
10 (normal) ...	8·4	43	112	387	126	30	14	Trace	356

Further details on soils from Esperance and Kellerberrin may be obtained from Professor Paterson's Report to the Royal Commission on the Mallee Belt and Esperance Lands, 1917.

Several features are worthy of note:—

Table 3.

1. A very high content of nitrate in the Merredin soil. This figure corresponds to about 1,200 ppm in the soil solution and compares with rich alluvial soils of California (7B, Table 1).

2. The poverty of the Wongan Hills and Chapman soils with respect to nitrate.

3. An almost complete absence of soluble inorganic phosphate in all soils. Top dressing of the Baker's Hill samples 2 and 3, probably accounts for the presence of soluble phosphate in these soils.

4. A deficiency of soluble calcium, as well as phosphate, in the sandy soils from Baker's Hill. The combination of these deficiencies is undoubtedly of great physiological significance and is suggestive as to a factor in the disorders among stock in the region.

5. Of the soils tested, the Wongan Hills soil was the only one from which a test for soluble manganese was obtained. Recent studies have shown this soil to be more than indicated by the 1 : 2 water extract, and the acid reaction (pH 5.64) is probably responsible for the higher content of soluble manganese.

Table 4.

The analyses were made by the Government Analyst on these soils and the figures are presented to illustrate the essential character of alkali soils —a concentrated soil solution. In these soils the bulk of the soluble material consists of sodium chloride. The soils are also rich in nitrate, potassium, calcium, etc., in solution, and would be very fertile but for the excess of sodium chloride. The analyses of sample 10 are given so that the alkali soils may be compared with a normal forest soil from Lake Brown.

The Effect of Additions of Soluble Phosphate.

It was thought that interesting results would be obtained from a study of the effect of phosphatic applications on the composition of the water extracts of soils from the State Farms. Three samples of each soil were taken and treated as follows:—

1. Moistened with distilled water to the optimum moisture capacity.
2. Moistened with distilled water containing phosphate equivalent to 52.4 p.p.m. of the dry soil.
3. Moistened as above, the phosphate being equivalent to 262 p.p.m. of the dry soil.

A solution of sodium phosphate was used as the source of phosphate.

The moist soils were stored in the laboratory and water extractions made after periods of one month and four months from the date of mixing.

Results of the analyses are reported in Table 5.

TABLE 5.

EFFECT OF ADDITIONS OF SOLUBLE PHOSPHATE ON THE WATER EXTRACT OF SOILS FROM WESTERN AUSTRALIA.

Soils were moistened with distilled water and with solutions of sodium phosphate. Analyses were made after standing for one month and four months after treatment.

(ppm Dry Soil.)

—	Distilled Water.		52·4 ppm PO_4 added.		262 ppm PO_4 added.	
	After 1 month.	After 4 months.	After 1 month.	After 4 months.	After 1 month.	After 4 months.
Merredin—						
PO_4 ppm	?	?	...	1·1	32	17·6
NO_3 ppm	193	206	182	208	190	190
Ghooli—						
PO_4 ppm	?	?	...	0·94	25	13·1
NO_3 ppm	59·5	171	54·5	72·6	50·6	83·2
Salmon Gums—						
PO_4 ppm	?	?	...	0·86	35	20·9
NO_3 ppm	39·7	44·0	45·6	45·6	30·7	37·6
Wongan Hills—						
PO_4 ppm	?	?	...	0·55	32·5	6·2
NO_3 ppm	10·9	16·8	Lost	48·0	10·9	45·6
Chapman—						
PO_4 ppm	?	?	3·6	0·63	50	22·1
NO_3 ppm	5·9	4·0	1·0	10·9	*Nil*	24·5

In each case the addition of soluble phosphate increased the amount of water soluble phosphate in the soil, but the bulk of the added phosphate was precipitated. The Wongan Hills soil, although a sandy soil, caused the greatest amount of precipitation.

This is probably due to the acid nature of the soil, such cations as manganese, iron and aluminium being effective agents for the precipitation of phosphate at this reaction (pH 5.64). The precipitation in the other soils was probably due to calcium and magnesium ions.

The additions of phosphate affected nitrification only in those soils which appeared naturally poor in nitrate—namely, those from Chapman and Wongan Hills. Approximately fourfold increases in nitrate were obtained in these soils as a result of the phosphate additions stimulating the soil micro-organisms.

These results suggest certain benefits from the superphosphate applications so general in Australia.

1. The soil solution is enriched in phosphate, the normal soil being extremely poor in soluble phosphate.

2. The improved phosphate supplies stimulate nitrification, particularly in soils lacking in nitrate.

3. By drilling the phosphate with the seed a concentrated phosphate solution is obtained in the immediate vicinity of the rootlets. Investigations have shown that soluble phosphate is needed in the early stages of crop growth.

SUMMARY AND CONCLUSIONS.

A general account of the work on the soil solution and the means of studying it has been given.

Work done on Western Australian soils, using the 1 : 2 water extract, is reported and the following conclusions suggested:—

1. The soils studied show a very wide variation in the concentration and composition of the soil solution as illustrated by the water extract.

2. There is almost complete absence of soluble phosphate from the soils under consideration.

3. Darling Range soils may be deficient in soluble calcium as well as soluble phosphate.

4. Additions of soluble phosphate increase the concentration of the water extracts with respect to phosphate. The acid "light lands" soil from Wongan Hills possessed the greatest power of precipitating phosphate in the range investigated.

5. Of those tested, manganese was present in the water extract of the acid soil from Wongan Hills only.

6. Sodium chloride is the predominant salt of certain alkali soils of Western Australia. The alkali soils from Lake Brown were rich in the minerals required for crop growth.

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